A SCINTILLATION-SOLID STATE DETECTOR FOR NON-DESTROYING SYNCHROTRON DIAGNOSTICS FOR HIGH ENERGY PROTON BEAMS

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Abstract

The opportunity of application of a method not destroying infra-red (IR) synchrotron diagnostics for measuring intensity and a structure of a proton beam in synchrotron using scintillation-solid state detector (SSSD) is considered.

INTRODUCTION

Synchrotron radiation (SR) is generated by relativistic protons at their passage through area of sharp change of intensity of a magnetic field at edges dipole magnets of the accelerator. In proton ring accelerators of SR it was experimentally observed and used for diagnostics of a beam with energy above 250 ГэВ [1]. In experiments for registration of radiation were used photoelectronic multiplier and semi-conductor gauges.

However for the decision of similar tasks application of photoelectronic multiplier is limited for the following reasons: big size of photoelectronic multiplier, a high working voltage, low noise immunity from electromagnetic fields, and use semi-conductor gauges not always probably because of their signal-noise owing to absence of the appreciable internal amplification similar to amplification SSSD (10^5 … 10^6). SSSD has not above listed lacks. This technology of SSSD creation develops actively last years in Russia [2] and abroad.

SOLID STATE SCINTILLATOR DETECTORS

A typical solid-state photomultiplier receiver contains [3] a matrix (an ordered array) of *pn*-junctions (pixels) with dimensions of the order of (30 □30)·10^{-3} mm, mounted on a common substrate. All the pixels are joined by aluminum buses, and the same bias voltage is applied to them. This bias voltage exceeds the breakdown voltage (20–60 V), which means that the device operates in the Geiger mode. The outputs of the all the pixels are connected to the common output of the device through load resistors. Each *pn*-junction operates in the Geiger mode with a multiplication factor of 10^6, but the whole matrix acts as an analog detector, since the output signal is equal to the sum of the signals of the *pn*-junctions, generated by the photons absorbed by them. A light quantum incident on the active part of the pixel generates a primary electron, which produces a discharge in the pixel, which is extinguished when the voltage on the pixel falls below the breakdown voltage. Quenching, i.e., cessation of the discharge, occurs when the voltage on the *pn*-junction falls below the breakdown voltage due to the presence in each pixel of a current-limiting load resistor. The current signals from the operating pixels are added in the common load. The particular features of operation in the Geiger mode is the linear dependence of the pixel gain on the bias voltage and the low requirements imposed on the temperature and supply-voltage stability compared, for example, with avalanche light-emitting diodes.

Because of its advantages, solid-state photomultipliers can successfully replace vacuum photomultipliers in the measuring system [4]. For this purpose, using solid-state photomultipliers, we developed a combined ionizing radiation detector for detecting x-rays, gamma rays and neutrons, together with a solid-state scintillation detection (SSSD) unit [5, 6]. It consists of a scintillator, a solid-state photomultiplier, a preamplifier, a casing and an electrical connector. In Fig. 1, we show a diagram of one version of this system – the BDST-10P, which has the following basic characteristics: volume of the CsI (TlI) scintillator 16 mm3, counting efficiency ~10 pulses/μR (137Cs), measured energy range 10–3000 keV, temperature range from –60°C to +60°C, energy resolution with respect to the 662 keV not more than 10%, permissible load not less than 105 pulses/sec, dosage power measurement range not less than 5·10–8–0.3 Gy/h, power supply 5 V, 5 mA and 24 V, 100 μA, diameter 13 mm, and length 80 mm.

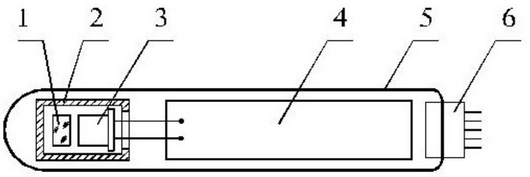

Figure 1: Sketch of the BDST-10P.
1) scintillator; 2) body; 3) solid-state photomultiplier; 4) electron preamplifier; 5) body of the detection unit; 6) plug.

Table 1 lists the merits and advantages of the solid-state photomultiplier, where we compare the characteristics of the solid-state scintillation detector (SSSD) and other combined CsI(Tl)-scintillator-photoreceiver detectors, such as the vacuum photomultiplier and pin and avalanche light-emitting diodes. It follows from the table that the SSSD is superior in a number of parameters to traditional detectors, employed in nuclear and accelerator techniques. The built-in preamplifier enables the SSSD to be employed directly with a standard spectrometer. The experimental equipment contains the object being investigated (the source of ionizing radiation), a combined detector and preamplifier, an amplifier-shaper, a spectrum analyzer and a computer.

Table 1: Comparative Characteristics of the Solid-State Scintillation Detection Unit and Other Light Detectors with a CsI(Tl) Scintillator

Characteristic	**CsI(Tl) scintillator + detector**			
	photomultiplier	**pin-light-emitting diode**	**avalanche light emitting diode**	**SSSD**
Recorded γ-quantum range, keV	$10–10^7$	$60–10^7$	$60–10^7$	$10–10^7$
γ-radiation dose operating range, R/h	$10^{-5}–40$	$10^{-5}–4$	$10^{-5}–4$	$10^{-5}–40$
Gain	10^6	1	150	10^6
Supply voltage range, V	500 – 1500	40	200	22 – 50
Operating temperature range, °C	± 60	–40 ... +30	–40 ... +30	± 60
Effect of magnetic fields	considerable	zero	zero	zero
Effect of mechanical loads	considerable	negligible	negligible	negligible
Detector volume, mm^3	10000	100	100	10
Operating life	limited	unlimited	unlimited	unlimited

By comparison with similar detectors, the SSSD has the following advantages (see the table): high photon recording sensitivity in the visible-light range and a high signal level at the output (106 electrons for each recorded light photon), sufficient energy resolution, particularly for low energies, compactness, mechanical durability, low supply voltage, stability, resolution time ~10 psec, wide operating temperature range, practically complete absence of a dependence of the parameters on magnetic fields, simplicity of the following electronic device, a high statistical load, long operating life, etc.

Moreover, the SSSD possesses wide possibilities for use in nuclear physics and power engineering. The simultaneous determination of the spectral characteristics of the radiation and the dosage power enables the information content of technological and dosimetric apparatus to be increased considerably. For technological apparatus for monitoring activity during production, a spectrometer with an SSSD enables one to determine the isotope responsible for an increase in the radioactivity of technological objects, for example:

- The nuclide composition of nuclear reactor coolant, enabling an important safety parameter, namely, the hermetic sealing of the fuel elements, to be monitored.
- Technological monitoring when separating isotopes, etc.

CONCLUSIONS

In conclusion we note that, by appropriate calibration of the apparatus, the diagnostic instrument described should find application as a monitor for measuring the absolute intensity of accelerated proton beams and the energy release in the subcritical blanket. The above-mentioned advantages of the SSSD enable it to be used successfully in the design of measuring equipment, developed at the Joint Institute for Nuclear Research, to investigate high-speed processes in experimental electronuclear power equipment based on a proton accelerator.

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